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# A study of the relationship between the exploitation and subsidence of Salmas

**Esfandiar Abbas Novinpour**[1]-*A member of the faculty of the Department of Geology, Urmia University, Urmia.*

**Abstract**
Salmas plain is located at the west of Uremia lake and at the 75 km of north of Uremia city. The main river of the plain, called Zulachai, is drained into Uremia Lake. Salmas aquifer is one of the coastal aquifers of Uremia Lake and has hydraulic connection with the lake. The recent draught occurrences and increased water consumption in agriculture and drinking sections water have not only caused regression of lake water, but also effected on coastal aquifer, such as Salmas plain aquifer. Over the long-term, average groundwater level in the Salmas aquifer has dropped sharply to 18/05 meters (averaging about 0/44 meters per year) and there has been 241 million cubic meters of reservoir capacity reduction. Salmas plain has two confined and unconfined Aquifers. Salmas annual depletion of groundwater resources in the study area during the water years of 2014-15 has been equal to 146 million cubic meters. The effects of land subsidence have been observed in some output areas (Kalshan and Qareh Qeshlaq areas).

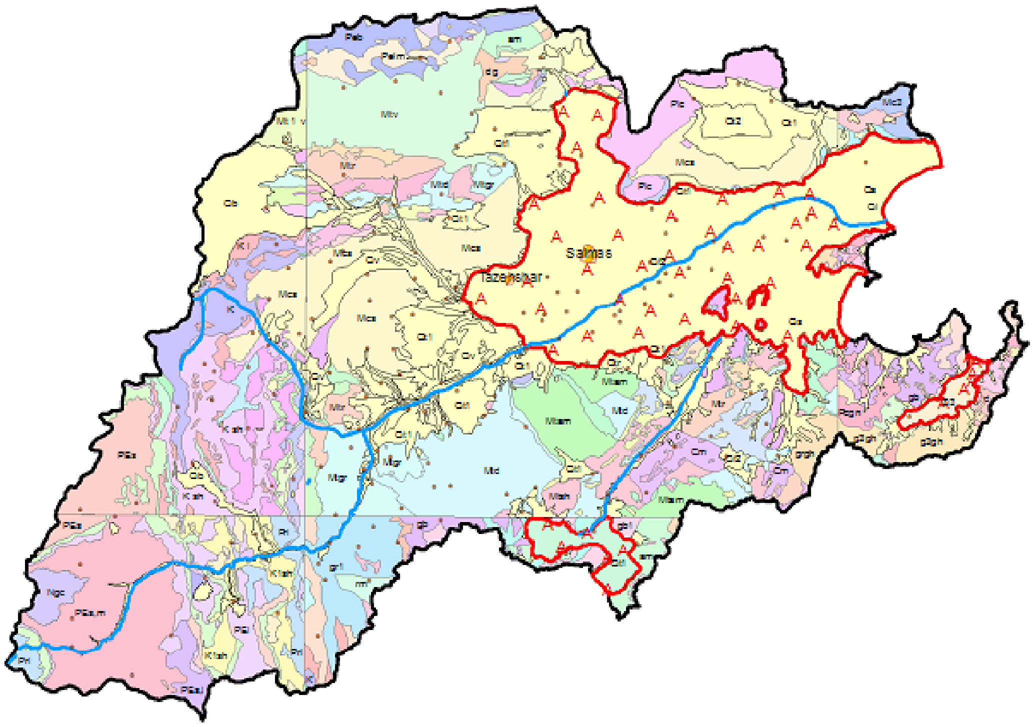
**Key words:** *Salmas, water substrate subsidence, water storage deficit, the groundwater hydrograph, ground subsidence, coastal aquifer.*

1.Corresponding Author, Tel: 0914318096 Email Address: novinpour_e@yahoo.com

## Introduction

The study area of Salmas is located in the north of the study areas of Uremia and in the west of Uremia Lake. The study area (that is according to the catchment area of Zulachay) is bordered by Turkey. Salmas Plain study area is 2749 square kilometers area and the scope of Salmas plain is 445 square kilometers. The maximum altitude of area is 3200 meters, its minimum is 1280 meters (on the sidelines of the lake), and an average elevation of Salmas plain is 1340 meters above free seas levels. Zulachay River with several major and minor branches transfers precipitation of region to Uremia Lake. The long-term average rainfall in the basin is 300 mm per year. The study area of Salmas is located between 44 º13 'to45º10 'E and 37 º 51' to38º 22' northern latitude. The study area of Salmas is in the group of a very cold- temperate climate and it has frigid winters and temperate summers. The average of annual rainfall in heights and plain are estimated to be 383 and 264 mm, respectively. The area is in western north of Iran and according to the divisions of the structural units (Ashtuklyn 1968), this area has been known as a part of metamorphic belt, ophiolite zone of Sanandaj-Sirjan. Geological composers of plain margin are mostly formed by Igneous and metamorphic and in a small area sedimentary formations that include Permian limestone and marl and sandstone rocks of the Qom formation. Out 445 square kilometers area of plains of Salmas, 399 km is under the coverage of moderate and severe Piezometric network. 39 wells have been drilled in the plain to study fluctuations in groundwater levels. Due to other study resources, there is selective quantitative and qualitative network of water resources with an area of 399 square kilometers, including 38 wells, 2 springs, and 2 aqueducts in Salmas plain. In order to estimate depletion and qualitative changes, every year in the Exploiting season, monthly measurement of water discharge and sampling twice a year for qualitative analysis are performed. The average level of underground water in the entry sections of Salmas plain is 40 meters and in the output section of plain is 5 meters. Salmas plain has two confined and unconfined Aquifers. In the study area of Salmas, totally 1382 wells (deep and semi-deep) have been drilled. Other water resources of the plain include 27 springs and 59 aqueducts. The annual depletion of groundwater resources in the study area of Salmas has been equal to 146 million cubic meters during the water years of 2014-15. Salmas plain water quality is suitable for drinking and agriculture and water type is more of Bicarbonate, sodic and calcic. In addition to the decline in groundwater levels, according to Kymograph charts of the plain of Salmas, the average electrical conductivity of the aquifer increased from 961 Micromhos cm in 1999 to 1126 in 1394, which represents a decline of groundwater quality over time.

Exploration drillings in this area in the years 1970 and 1975 have been done in the number of 56 exploratory wells, 17 adjacent piezometers rings (in alluvial formation). Geophysical studies have been conducted in the study area Salmas with a geoelectric method. Alluvial deposits of plain of Salmas are coarse grains in the input fields and sidelines (rubble- sand) and are gradually finer grain and with silt and clay in central and output parts of plain. Presence of impervious sediments (silt and clay) and or with less permeability, along with the frequency of sand, the have caused creation of under pressure layers in this area. Unconfined Aquifers in the central and output sections of the plain are wider, especially, in the central areas, (around Sultan Ahmad and Agha Ismail villages) had a great deal of pressure in past. Two confined and unconfined aquifers of Salmas plain have hydraulic connection naturally in some areas of the plain (Due to the confining layer of texture and less compression). The average thickness of unconfined aquifer of Salmas plain is 35 m and the confined layer is 90 m. the maximum thickness of the aquifer has been recognized to be up to the




Map1. The location of Basin and the plain of Salmas

200 m depth. Evaluation of pumping tests of 12 new wells in the plain of Salmas shows the increased amount of transmissivity of aquifer from margin to the Center of the Plain that is because of increased thickness of aquifer. In addition to the thickness of aquifer, along the Zola river, this increase can be effected by changes in way of gradation of alluvium and it high permeability. The maximum transmission capacity is more than 3000 square meters per day and a minimum is 50 square meters per day (at the edge of the plains) respectively. Calculated storage coefficients by exploration of wells do not have the appropriate spread on the plain. Salmas plain storage coefficient is estimated at around 3%. Formations with the possibility of storing water in them include Qom limestone formations and Ruteh with an approximate area of 150 square kilometers. Among Non-carbonate formations having storages with poor storage volume or being effective in nutriment of alluvial aquifers, Precambrian metamorphic rocks, sandstones of the Qom Formation and conglomerate and marl Miocene – Pliocene can be mentioned.

**Materials and methods**

Salmas plain studies date back to the '40s, but Piezometric network measurement and unit hydrograph drawing started for the first time in the water year of 1975-76. Unfortunately, because of Thiessen network change and the lack of data in some water years due to a drop in the level of groundwater, a long- term drawing of hydrograph of the plain continuously was not possible. Therefore, statistics of the mentioned years were completed based on the piezometers wells remained from those years, and after completion of long- term hydrograph, according to standard methods, the long- term hydrograph was leveled. A look at the forty- one year period from the water year of 1974-75 to 2014-15 shows during this period, from water year of 74-75 to 1994-95, fluctuations of the level of aquifer were normal. The droughts at the beginning of 60 decade caused a drop of about 2 meters in ground water level, but an increase in precipitation in the late 60's and early 70's compensated this drop.

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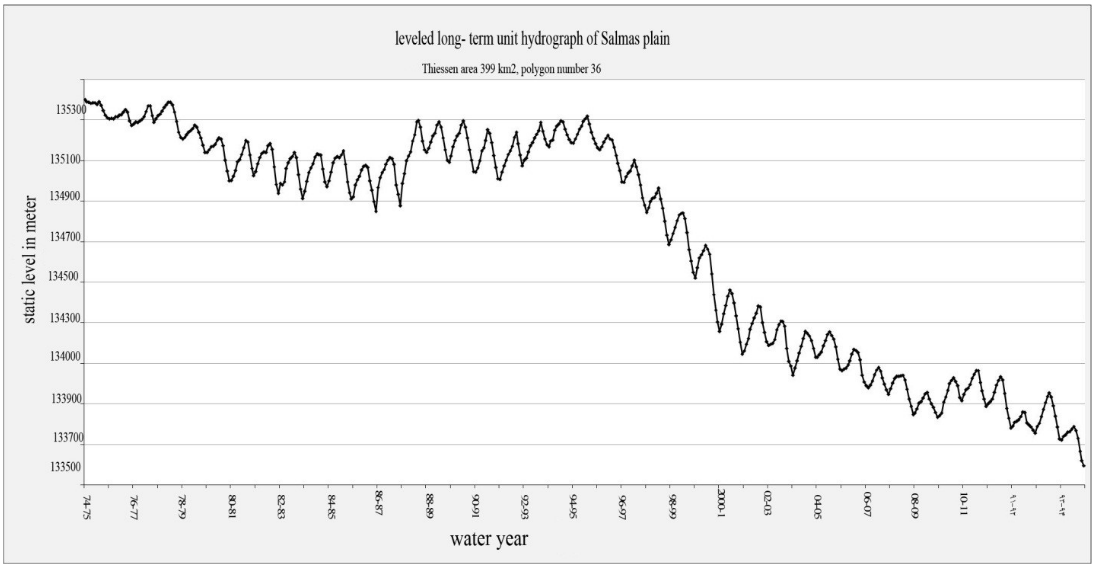


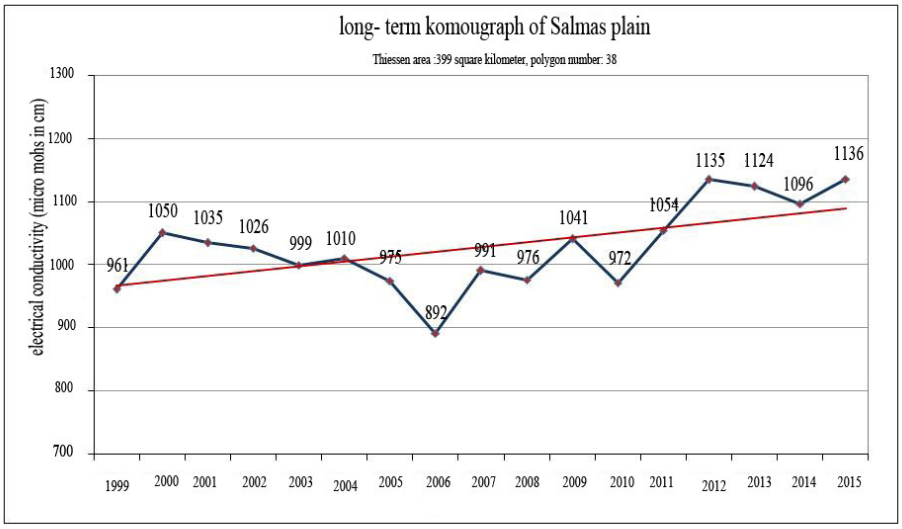


Unfortunately, by restart of drought, from the water year of 95-96, and simultaneous increase of the rate of exploitation, severe subsidence of the aquifer started leading to issuing the first notice prohibiting the development of groundwater exploitation for a part of plain of Salmas (input areas of the Plain in West of uremia-Salmas Road) in 2000. Increased rainfall in the early 80s could not prevent the decline of water aquifer, therefore, now all ranges of Salmas studies have been banned. The following graph shows the changing trend of the level of groundwater of Salmas plain aquifer in the form of a long-term unit hydrograph of Salmas plain.

The graph below shows the trend of long-term quality of Salmas aquifer based on the samples taken from electrical conductivity of selected water of the plain.

Subsidence or ground collapse occurs in the wake of the increasing exploitation of groundwater, especially in basins with alluvial deposits where a shallow sea or unconsolidated lake has been accumulated. According to the definition of geology institute, subsidence phenomenon includes collapse or subsidence of land surface downward that can have a little horizontal displacement. Movement is not limited in regard with intensity, vastness and the involved areas. In addition, subsidence can be created due to the effects of natural geological phenomena such as solubility, melting ice, slow movements of the crust of the lava exit from the Earth's crust, or human activities such as mining, harvesting, ground water, or oil. However, the main reason witnessed in the recent years and everyone can agree on it, is overexploitation of groundwater and surface water supplies and consequently subsidence of layers of earth. Subsidence of an area occurs mostly because there are compressible layers in the depth of earth that are destroyed with the withdrawal of ground water and layer depletion, the water that tolerated the weight of upper layers. Moreover, sediments that can be compressible will lose their volume, and as a result, they will alleviate.

Ground subsidence is a phenomenon that happens during time and is felt less. It is a phenomenon occurring in a plain area and its rate is a few millimeters to a few centimeters per year. Moreover, in comparison with sinkholes that are limited and sudden phenomena, creating a crater 30 meters in diameter, areal subsidence occurs gradually and progressively. As the consequences of subsidence are not simply recognized, it threaten all infrastructures and vital streams and often when find it out, it might be too late. The damage made by subsidence is over time and is sensed less, but if sinkholes are in a region or an area with life going on, there will be many risks. Consequently, due to the emergence of more sinkholes in the plains of the country, the danger of this phenomenon is felt closer than before; a risk that can digest buildings and endanger lives of hundreds of people.

Damages made by subsidence and earth cracks are largely irreparable, costly, and destructive. For instance, subsidence can lead to the destruction of irrigation systems and agricultural fertile soils. Damage to wells in the rural and urban subsidence areas is very common. It causes wells destruction as well as a phenomenon called" well growth" or tube- making; In this phenomenon, it seems the well tube comes up from the surface of ground, while the tube is stable, and the level of ground has gone down. Urban areas are particularly vulnerable due to population density, buildings, and Lifeline. This phenomenon can damage streets, bridges, highways, and foundation of buildings. It can disrupt pipelines, gas, and sewage and can cause cracking of buildings and other constructions and it is evident that in this case, structures having more the breadth and height are more vulnerable.

By making a change in topography condition of the area, Subsidence phenomenon can lead to significant changes in hydrology of the area. For example, in these areas, it is possible the giant and destructive floods occur, while there has not been any record of such floods before the subsidence. On the other hand, by making changes in hydrology condition of the area such as direction and speed of groundwater flow, groundwater balance, this phenomenon can make abnormal consequence. Linear structures such as railroad rails and pipes for gas and water are damaged with the occurrence of subsidence. When these structures face with subsidence on their ways, they will be in trouble that if we collect their costs, it will be a high digit.

In the present study, by relying on the phenomenon of growth of wells or tube making in piezometers of Salmas plain aquifer, the subsidence phenomenon in Salmas plain has been reviewed. Considering the records and information obtained from the periodic visits in Salmas plain indicating the presence of subsidence around a number of piezometers of eastern margins of Salmas aquifer leading to the well growth or tube-making phenomenon, Piezometers located on the eastern edge of the aquifer were visited during two stages in 2015 and early 2016. Moreover, the rate of subsidence observed around the new or old piezometers was recorded and some images were taken from the created consequences. The effects of ground subsidence have been observed in some output areas of the plain

(Kalshan, Kangarlou and Qareh Qeshlaq areas). All the piezometers on the eastern margin of Salmas aquifer located near Uremia Lake, as well as piezometers on the southern edge of the plain such as Kalshan, lands of Aliabad and Aq Ziarat experienced well growth or tube- making because of the ground subsidence phenomenon. According to the measurements, the rate of this subsidence is between the minimum of 5 cm and the maximum of 20 cm. The image below shows the decline of the Salmas plain at the location of piezometers of Kalshan village that is about 15 cm.

The image below shows the decline of the Salmas plain at the location of piezometers of Kangarlou village that is about 20 cm.

Sand- production of the exploitation wells is one of the other phenomena associated with groundwater in the plain of Salmas that is often observed in the eastern margin of the plain where the sediments are fine- grained. This phenomenon can be effective in increasing the amount of ground subsidence in this area. Subsidence and its unpleasant consequences have an irreversible process. They can be slowed down and controlled very hard. The base of each national movement to confront with the risk of subsidence is based on three principles of prediction, diagnosis and monitoring. Correct management of ware resources has a key role in prevention of this phenomenon. The process of prediction and recognition are based on the data obtained from well logging, geotechnical tests and geophysical engineering and geological data to predict and measure soil settlement and effective porosity and its compressibility potential. According to experts of Geological organization, some of strategies to slow down the process of development of subsidence include. _ reduction of exploitation of groundwater resources, especially in areas that are faced with large drop. _preventing sand and gravel mining in upland areas and within the scope of subsidence due to the negative impact of these perceptions on feeding the aquifer; _ Changes in cropping patterns and irrigation techniques such as sprinkler, drip and under pressure irrigation. _ greenhouse cultivation. _Not cultivating of non-strategic crops or the use of purified water of urban waste to reduce the exploitation of underground water. _ Changing patterns of water use in the industrial sector and the use of closed water cycles.

**Conclusion and discussion**

**A) Drop of groundwater level**

According to long- term unit hydrograph of Salmas plain, the annual average level of groundwater is 18/05 m and on average, it has dropped to 0/44.

**B) Reduction of the volume of storage**

In Salmas plain, considering the storage coef-

ficient and aquifer area, during a 41- year- long period, the shortage of volume of storage on average and in total has been estimated to be 5/78 and 240/97 million cubic meters, respectively.

ΔV=Δh×S×A=)0.44 × 0.03 × 445 × 106(/106= 5.87 MCM

ΔV=Δh×S×A=)18.05 × 0.03 × 445 × 106(/106= 240.97 MCM

C) – Reduction of the water discharge, displacement and excavation of exploitation wells

Every year, a number of the exploitation wells of the area are moved or excavated due to reduction of water discharge. In the other term, groundwater is extracted from the deeper layers.

D) Reduction of water discharge and or drains, aqueducts and springs become dry

During the recent years, water discharge of springs and aqueducts and drains of the output area of the drain have become fully dry.

E)According to Kymograph diagram of Salmas plain, the average of electric conductivity of aquifer has increased from 961 Micromhos on cm in 1999 to 1126 in 2015. This increase shows the quality drop of groundwater by passage of time.

F)The effects of ground subsidence have been observed in some output areas of the plain (Kalshan, Kangarlou and Qareh Qeshlagh areas).

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